宇宙線の気候・気象への影響を探る

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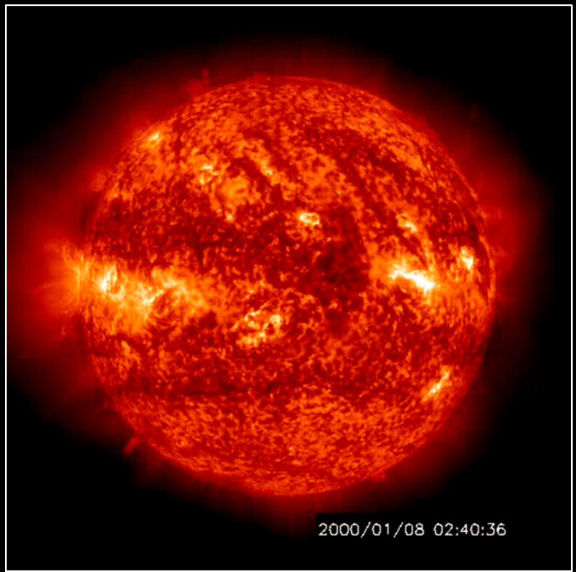
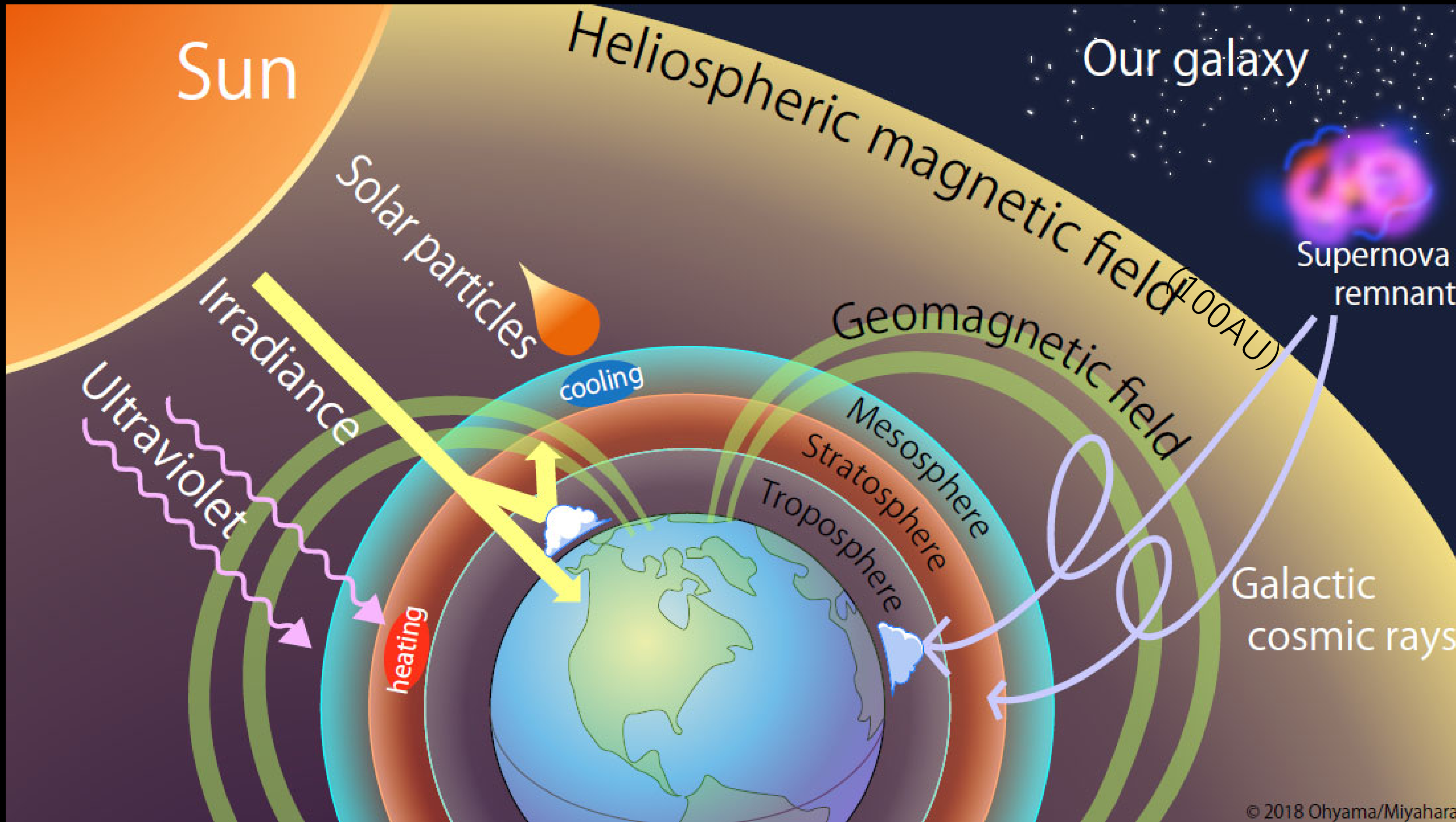
Possible external forcing of the Earth's climate



Solar activity
- Monthly
- 11-year cycle
- 200-yr cycle
- 1000-/2000-yr cycle

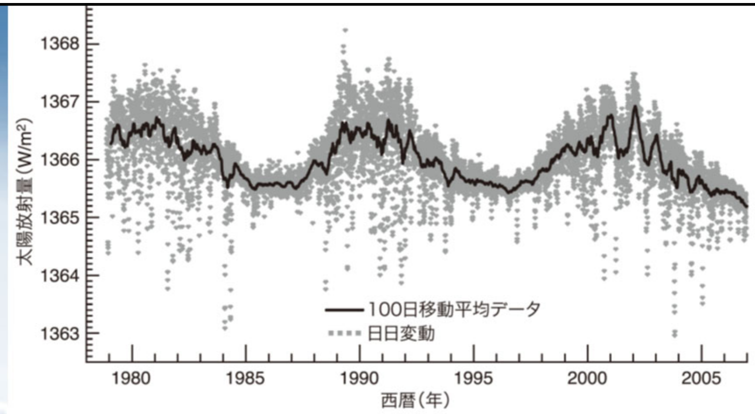
Geomagnetic filed
- ≧ centennial



Brief History

- (100-yr long debate on the possible Sun-Climate connection)
-
-

1980's Precise measurement of Total Solar Irradiance (~1W/m^2 variation)



1997 Discovery of GCR-cloud connection (Svensmark+1997)

2001 Correlation between solar activity and climate over the past 10,000 years (1000-yr, 2000-yr cycles) (Bond et al., 2001)

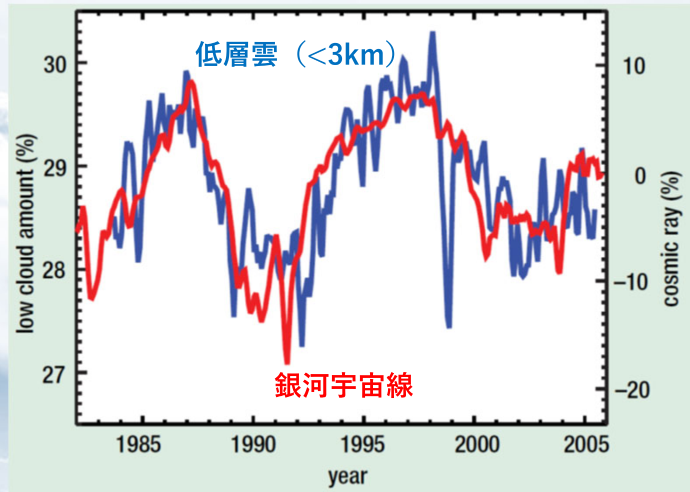
2005 Possible influence on the weather (monthly-scale cycle) (Muraki+2005; Sato+2005)

2011 First results from the CLOUD Experiment @ CERN (Kirkby+2011)

2019 Irradiance's impact amplified by a feedback mechanism? (Misios+2019)

2022 GCR's impact mediated by deep convective coulds? (Miyahara et al.)

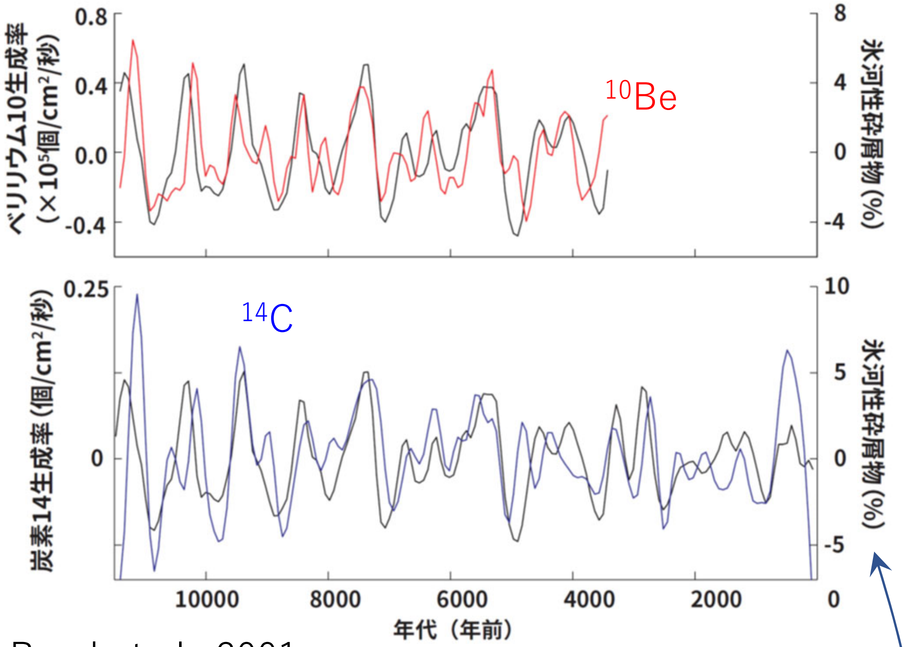
宇宙線と低層雲の相関



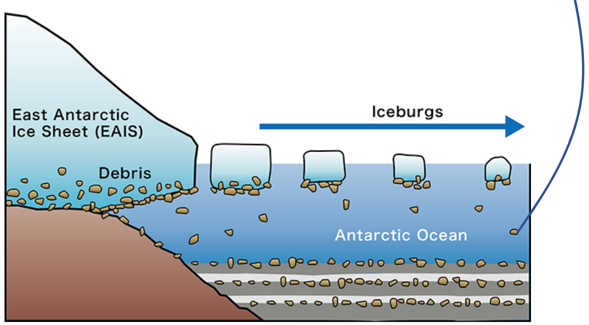
Svensmark, 2007

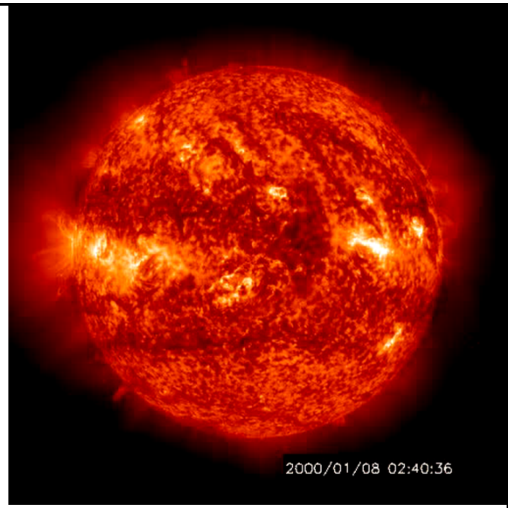
Example of Sun-Climate connection

Low solar activity → more iceburgs (low temperature)



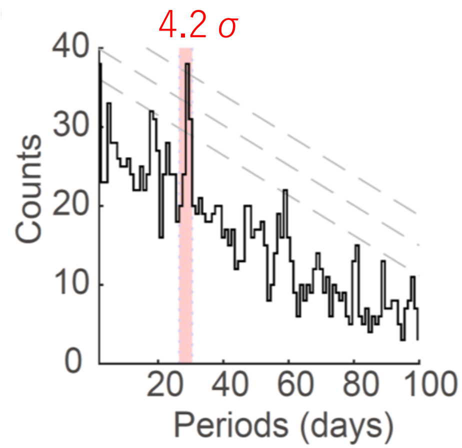
Bond et al., 2001

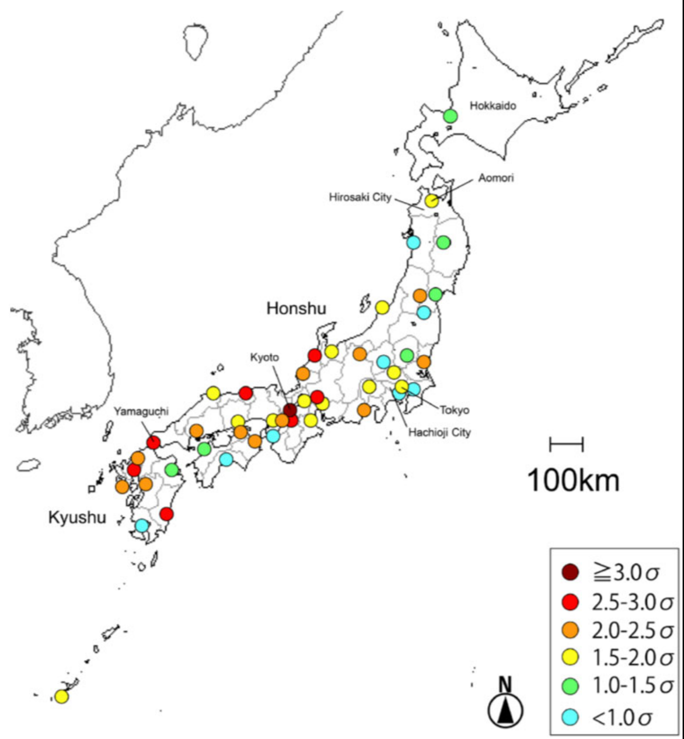




日本の夏の雷活動の～27日周期

Wide-area thunderstorm activity (covering ≧ 15 prefectures)

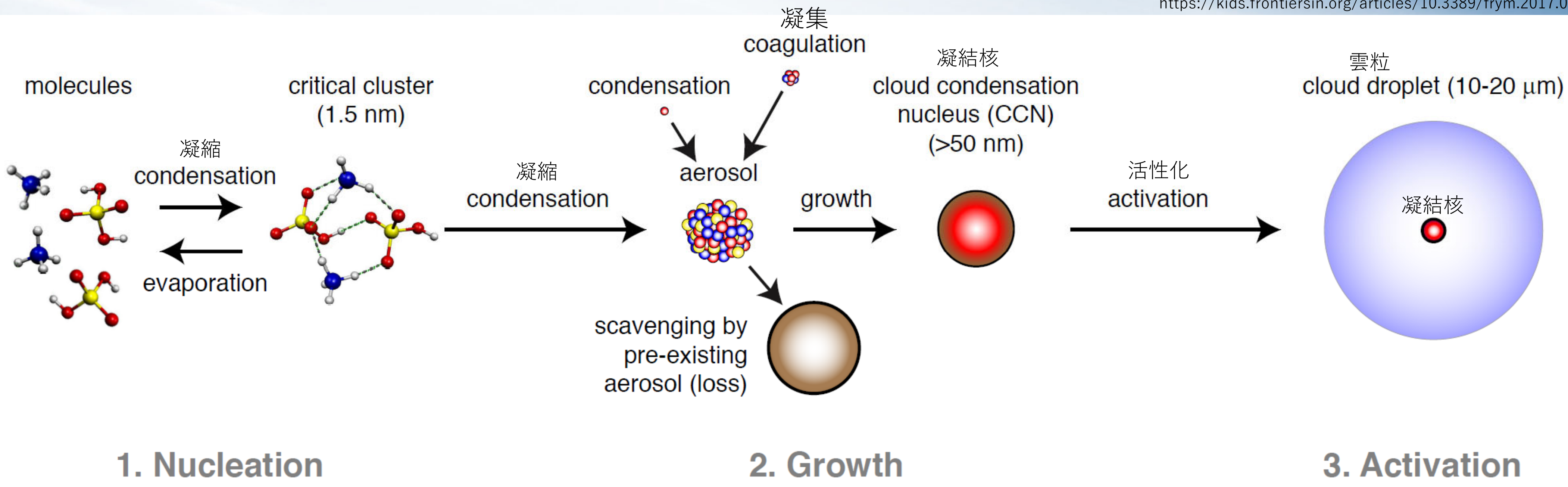




Miyahara et al., 2017

Possible contributions of GCR-induced ions

https://kids.frontiersin.org/articles/10.3389/frym.2017.00043



Ionization of biogenic molecules
& condensation (gas phase -> liquid phase)

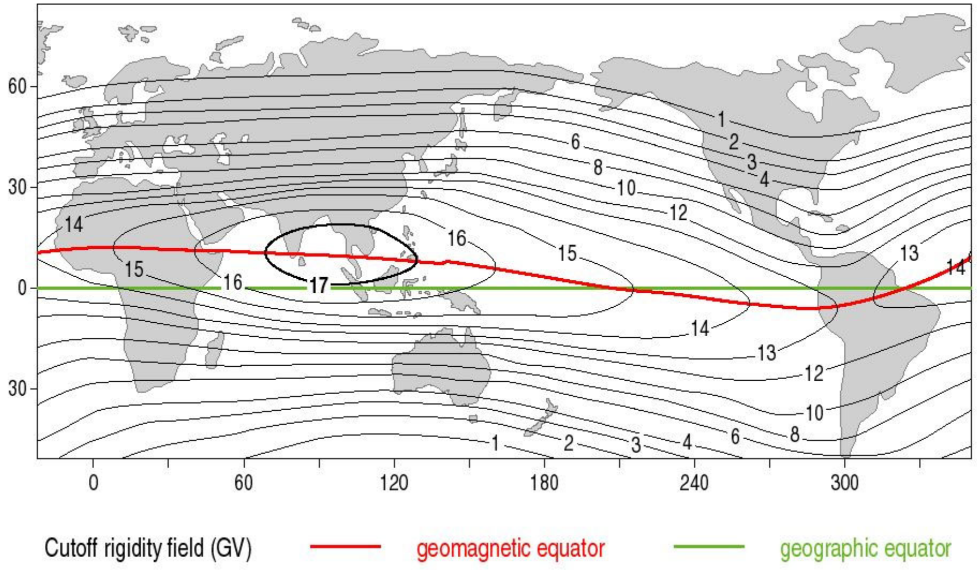
Stabilization of ice crystals from evaporation

Coagulation of aerosols

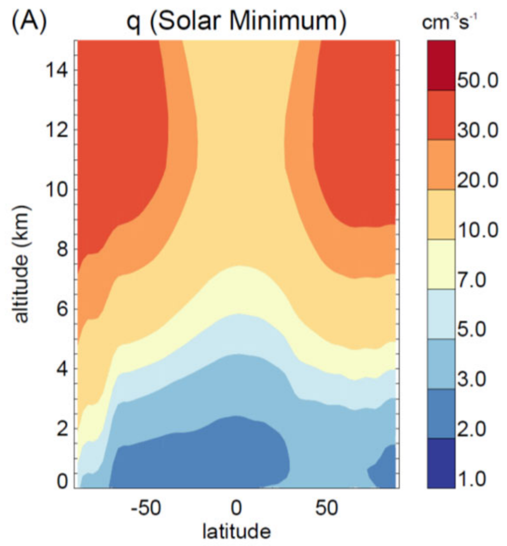
Promotion of coalescence between aerosols and cloud droplets

Equator or the polar regions?

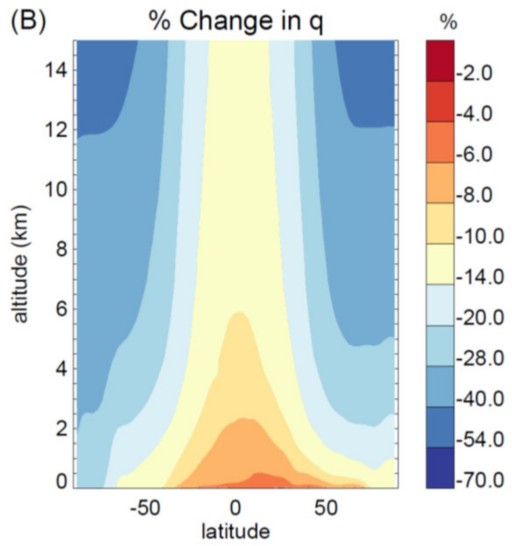
地磁気によるカットオフエネルギー（GV）



11年周期の極小



イオン生成率の偏差（%）



イオンの生成率としては極域が有利（特に対流圏上層）

From Dunne+2016

Equator or the polar regions?

ただしエアロゾルの素になる
生物起源ガスの面からすると
低緯度の方が有利

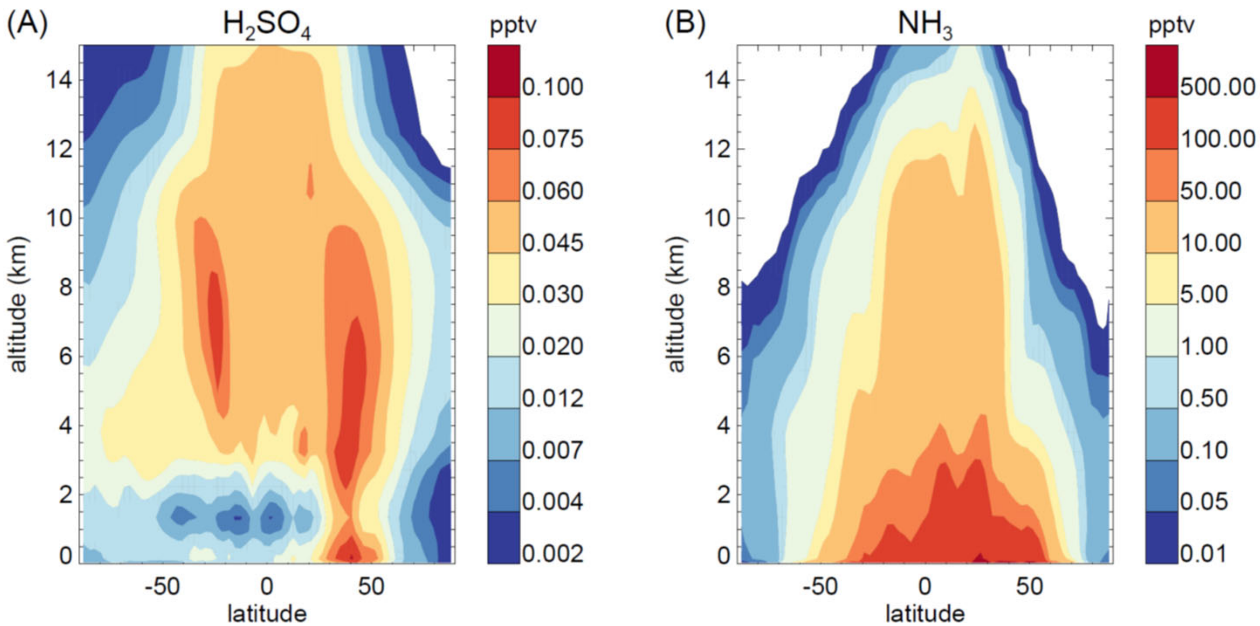


Figure S10: Vertical profiles of nucleating inorganic trace gases. Concentration of (A), $[H_2SO_4]$ modeled using GLOMAP-bin; (B), gas-phase $[NH_3]$ obtained from a GLOMAP-mode simulation using the EDGAR Emissions Inventory (*51*) and the particulate ammonium dissolution solver of Ref. (*94*). Both figures are annual mean values for 2008 and concentrations are shown as zonal means.

Dunne et al., 2016

Equator or the polar regions?

Kirkby et al., 2011 (CLOUD experiment@CERN)

チャンバー実験によると
気温は低い方が有利

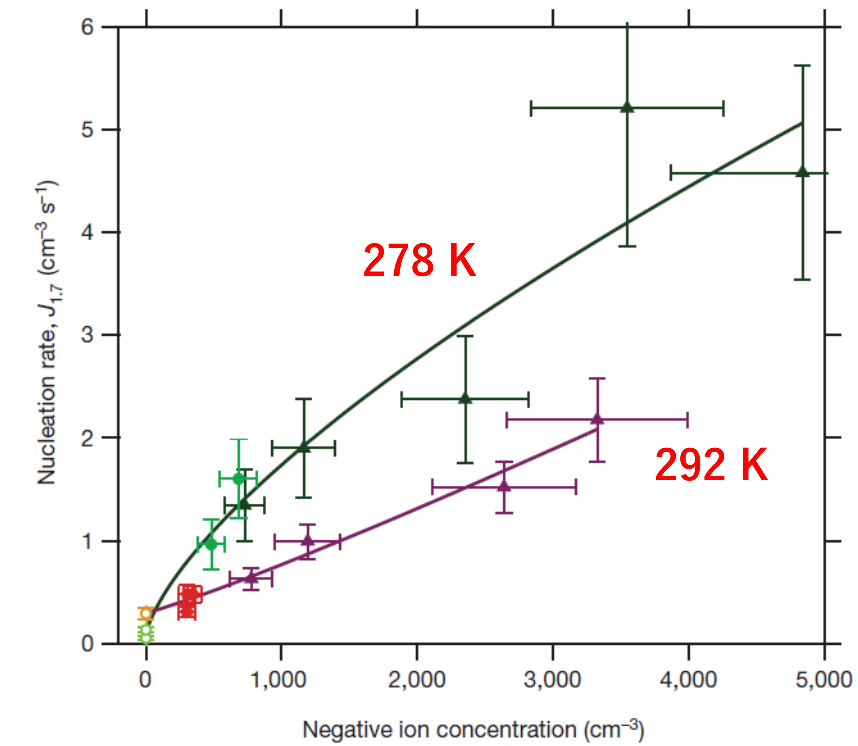
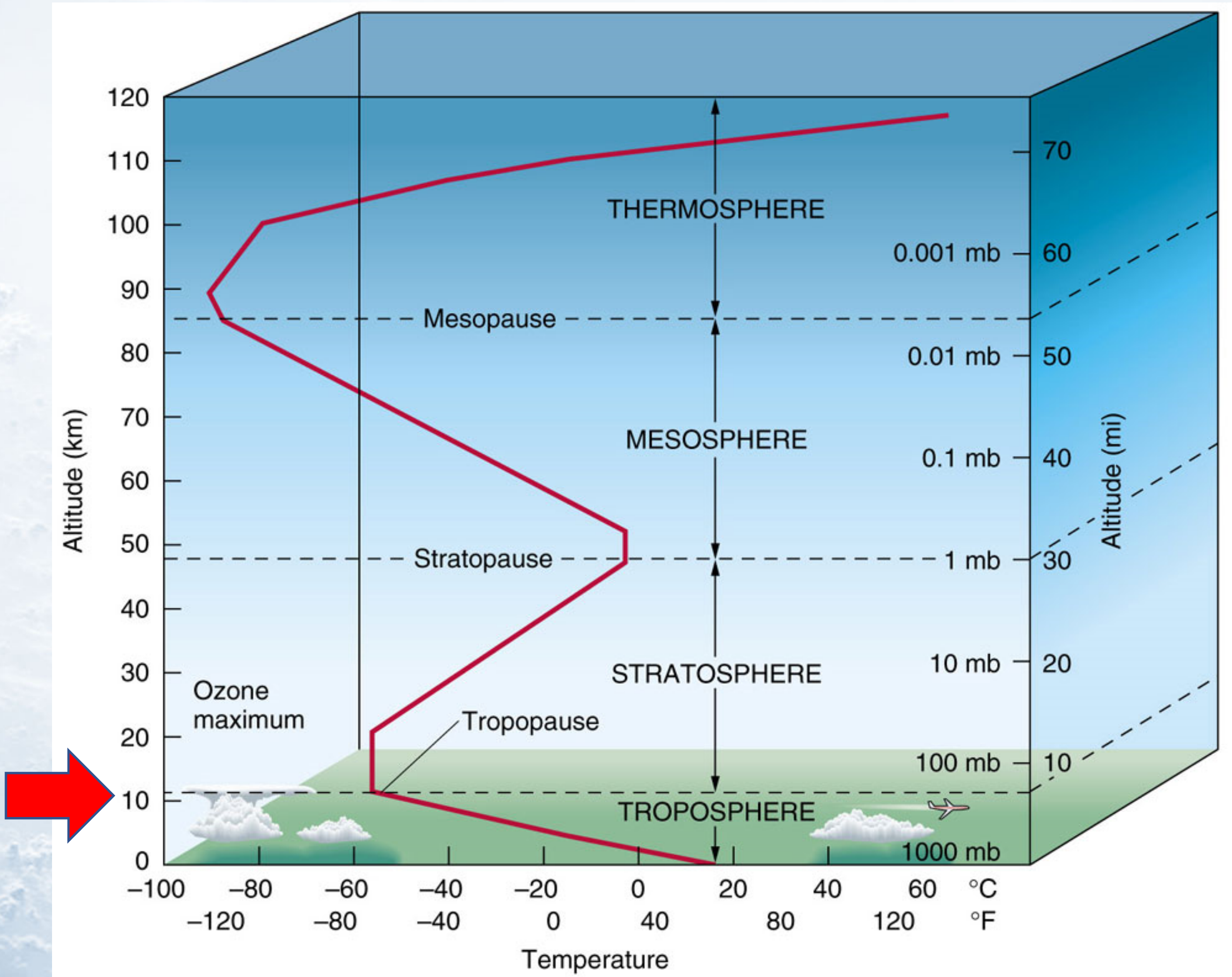


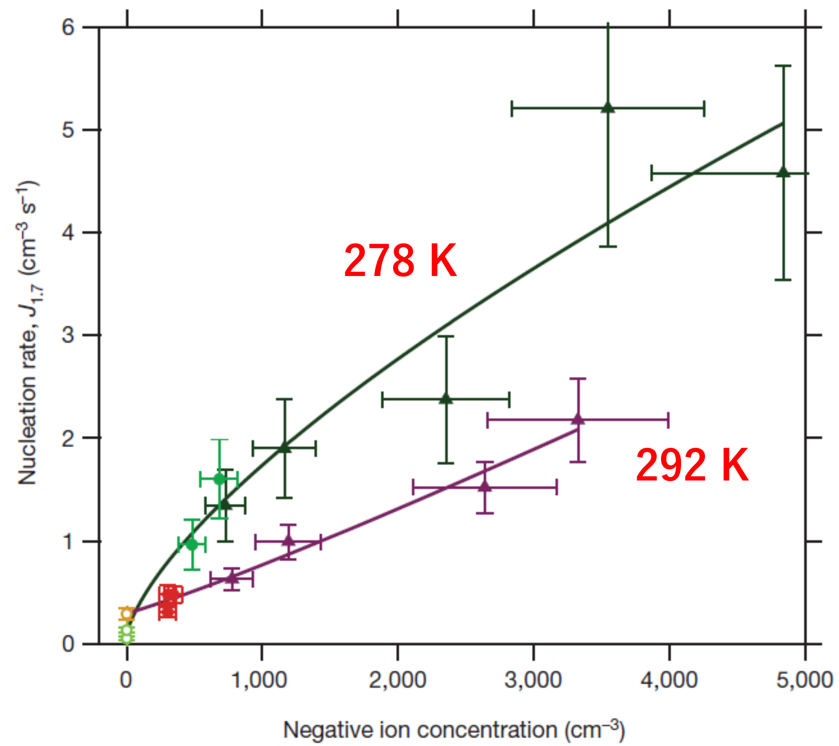
Figure 2 | Plots of nucleation rate against negative ion concentration. Nucleation rates as a function of negative ion concentration at 292 K and $[H_2SO_4] = 4.5 \times 10^8$ cm^{-3} (purple line), and at 278 K and $[H_2SO_4] = 1.5 \times 10^8$ cm^{-3} (green line). Triangles, J_{ch}; filled circles, J_{gcr}; open circles, J_n. All measurements were made at 38% relative humidity and 35 p.p.t.v. NH_3. Neutral nucleation rates, J_n, were effectively measured at zero ion pair concentration (ion or charged-cluster lifetime <1 s). The curves are fits of the form $J = j_0 + k[\text{ion}^-]^p$, where j_0, k and p are free parameters. The error bars indicate only the point-to-point 1σ errors; the nucleation rates and ion concentrations each have estimated overall scale uncertainties of ±30%.

Equator or the polar regions?

Kirkby et al., 2011 (CLOUD experiment@CERN)

１つの可能性：低緯度域の積乱雲（最大～16 kmまで発達）





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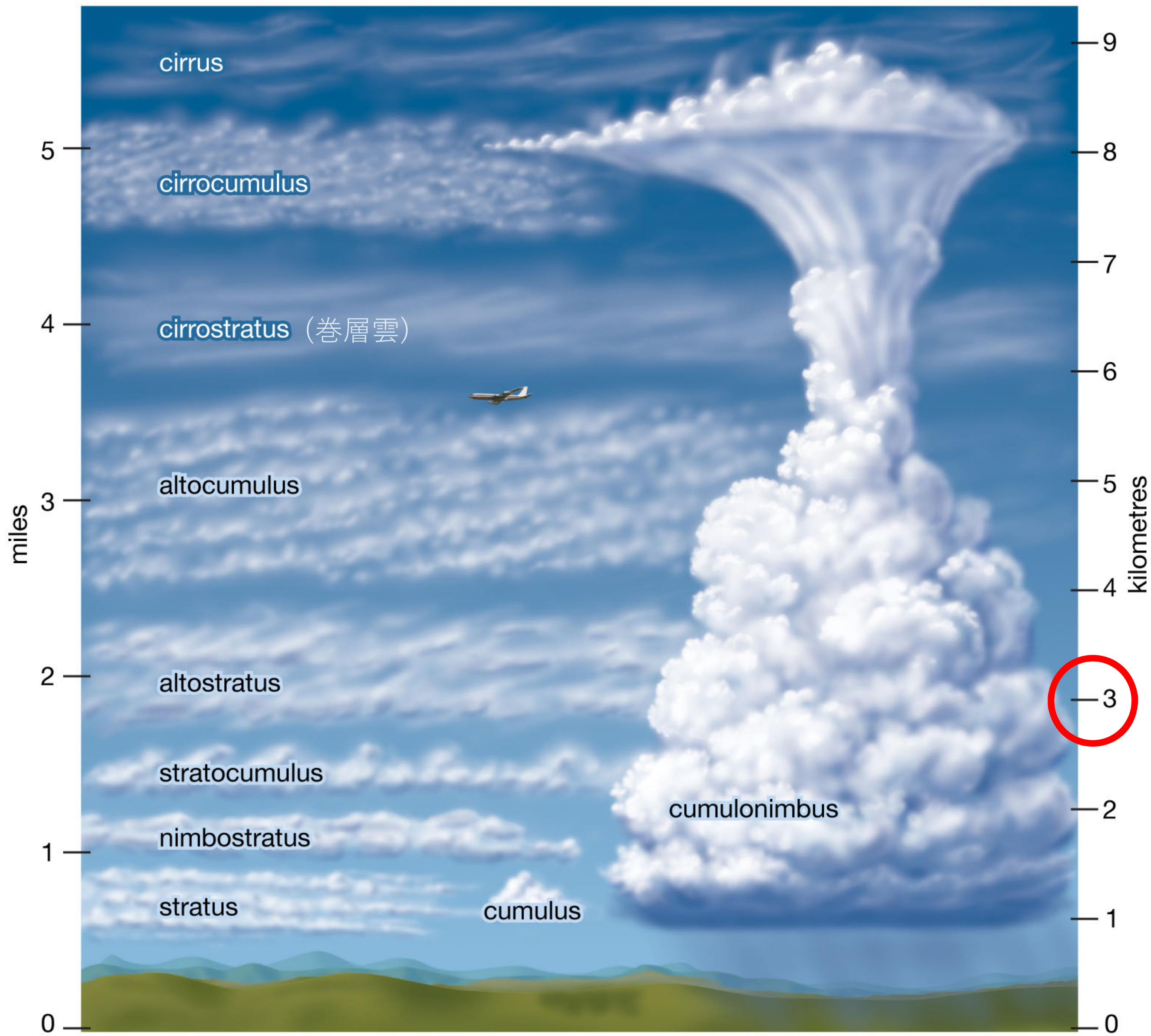
https://robertcarrollweather.wordpress.com/weather-education/weather-lessons/lesson-1-introduction-to-the-atmosphere-vertical-profile-of-the-atmosphere/

≦3kmは、既存のエアロゾルが多いことからも、
中層運〜上層雲が有利



Possible impacts of GCRs on deep convective clouds?

- Correlation between GCRs and high clouds for 1979-2021

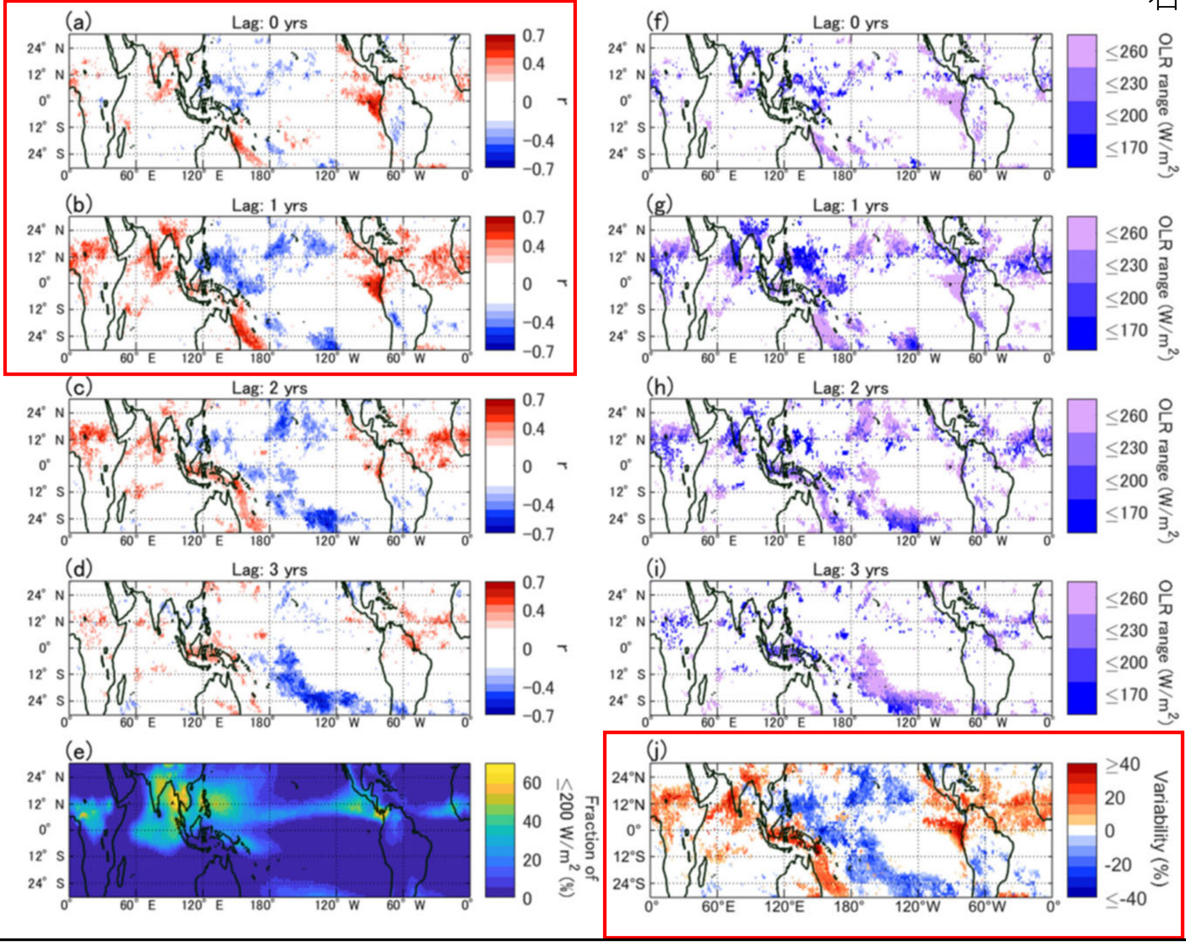
＝ based on Outgoing Longwave Radiation

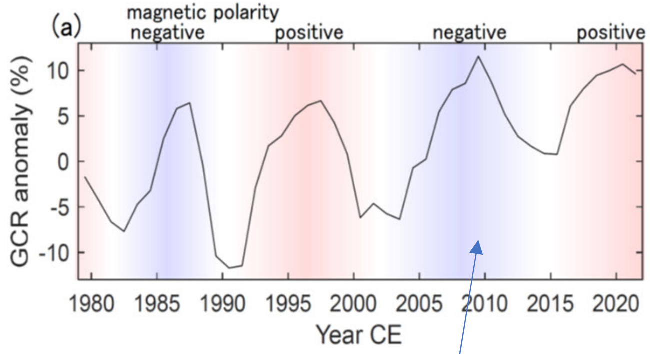
August　左側は相関マップ

右側のマップの味方

中層＋上層雲

上層雲のみ応答しているケース





GCRの
11年周期
＋少し22年周期

（相関を取る前に
長期トレンドは差っ引く）

- 陸＆陸に近い海で上層雲増（局所的）
- 太平洋では、宇宙線増 → 上層雲減

Miyahara et al. (https://doi.org/10.1002/essoar.10511359.1)

Possible impacts of GCRs on deep convective clouds?

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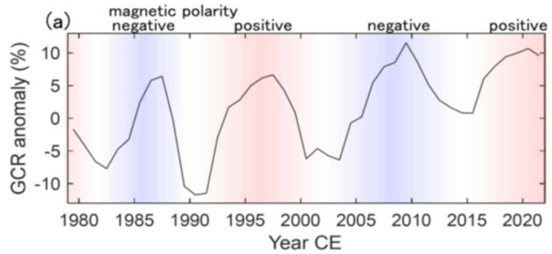
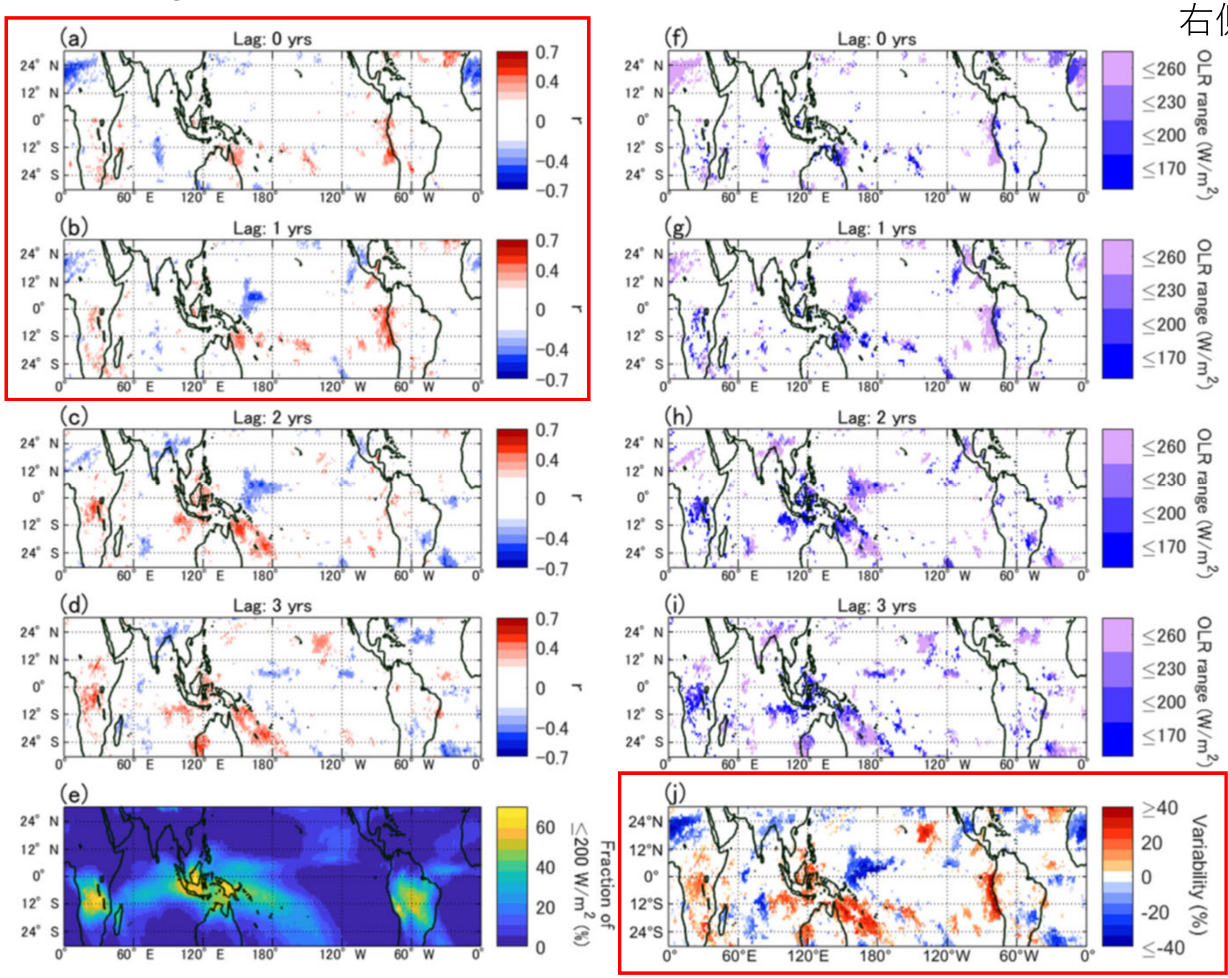


January 左側は相関マップ



右側のマップの味方

中層＋上層雲

上層雲のみ応答しているケース

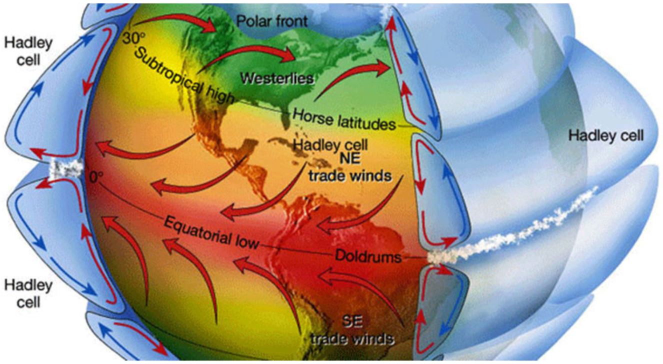
- １月は応答域が南半球（夏半球）に移動

  北オーストラリア、チリ周辺

Miyahara et al. (preprint)

Intensification of trade wind?

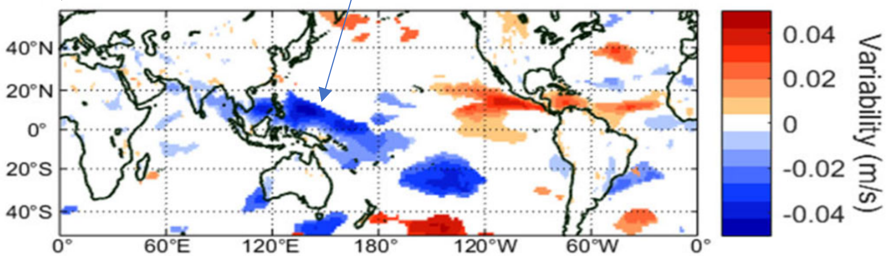
Miyahara et al. (preprint)

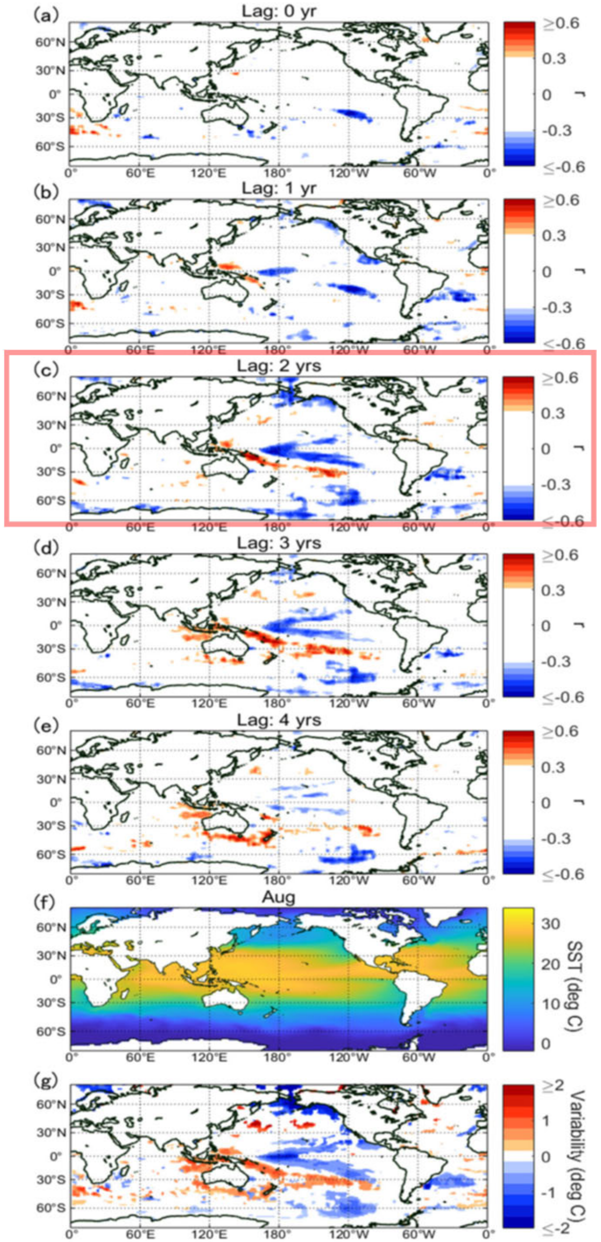


エアロゾル増
→積乱雲の中の潜熱増
→積乱雲発達
→上昇流強化
→西太平洋での貿易風強化

JRA-55 reanalysis data
(1979-2021)

宇宙線増化時の貿易風偏差

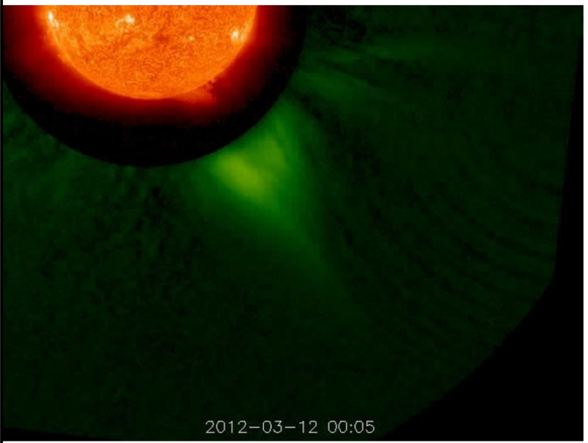


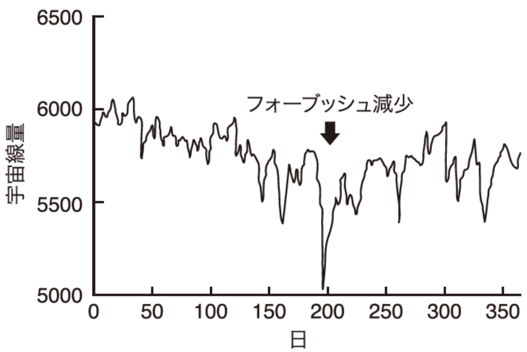


雲の応答にやや遅れて
影響最大化

11年サイクルでの
最大偏差：**~2 ℃**

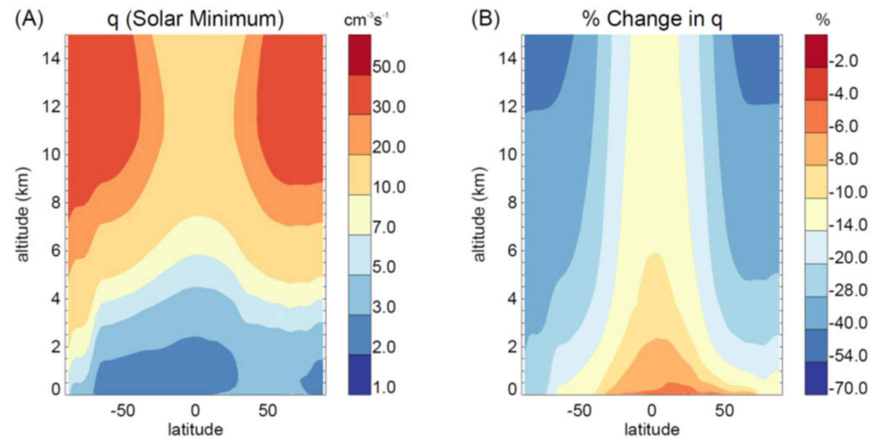
Imprints of daily-scale GCR variations (impact of Forbush Decrease)





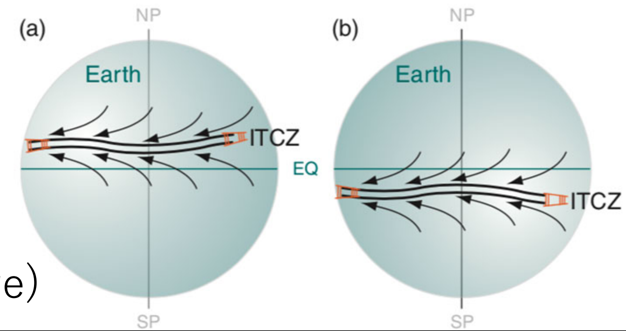
Miyahara et al., to be submitted.

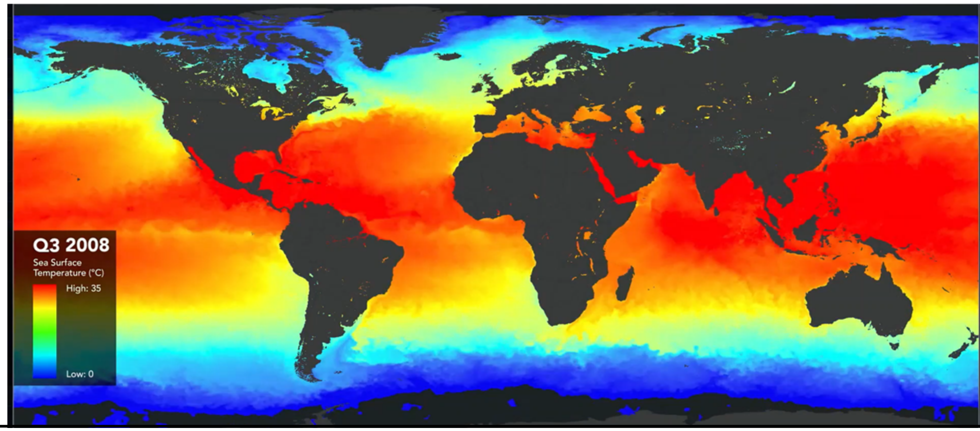
Possible key parameters



- Abundance of GCR-induced ions
- Low temperatures (e.g. high altitudes)
- Fewer pre-existing aerosols (> 4km a.s.l)
- Abundance of gas-phase aerosol precursors (tropics)
- Presence of marine aerosols (coastal area)
- Presence of deep convections (encounter between ions and aerosol precursors)
- Deeper convection over lands (overlap of the ITCZ on lands)
- Diurnal cycles (over lands)
- Excursion of ITCZ to the higher latitudes (encounter between ions and aerosol precursors)

ITCZ: Inter Tropical Convergence Zone (belt of low pressure)





Summary

- Correlations between solar activity and climate/weather have been observed at various time scales
- GCRs may contribute to the Sun-Climate connection through the impacts on the deep convective clouds
- Heliospheric environment is the important controlling factor of climate and weather
- Physical mechanism behind needs further examinations